U.S.NRC RIC 2016

Review of Fire Modeling Activities, 2000 to Present

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Timeline of NRC Verification and Validation Efforts

2001	NFPA 805 issued. All fire models shall be *Verified* and *Validated*.
2003	NRC sponsors fire model validation experiments at NIST.
2004	US NRC amends its requirements for fire protection to include 805.
2004	Fire Dynamics Tools (FDTs) published
2007	NRC and EPRI publish NUREG-1824, a V&V study of five models
2008	Fire Modeling PIRT (Phenomena Identification and Ranking Technique)
2008	PRISME 1, French V&V study, including NRC as a member
2012	NRC and EPRI publish NUREG-1934, Fire Model User's Guide
2016	Fire Model V&V, NUREG-1824, Supplement 1

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ACRS recommendations following the publication of the original V&V study:

1. "… provide probability distributions for the model predictions due to the intrinsic model uncertainty, i.e. the uncertainty associated with the model's physical and mathematical assumptions.

2. "… provide estimates of the ranges of normalized parameters to be expected in nuclear plant applications. These estimates would allow a determination of whether risk-significant fires fall within or outside the parameter ranges covered by the verification and validation process."

Reference: ACRSR-2219, Advisory Committee on Reactor Safeguards, 2006.

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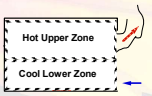
Models Selected for NRC/EPRI V&V Study

Fire Dynamics Tools (FDTs)	NRC Spreadsheets
FIVE-Rev1	EPRI Spreadsheets
Cons. Fire & Smoke Transport (CFAST)	NIST zone model
MAGIC (EPRI/MOU)	Électricité de France zone model
Fire Dynamics Simulator (FDS)	NIST CFD Model

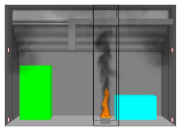
Empirical Models

$$L_f = 0.23\dot{Q}^{2/5} - 1.02D$$

Zone Models



CFD Models



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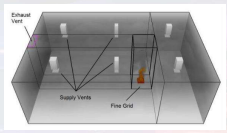
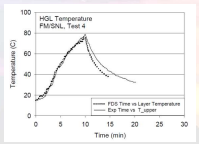
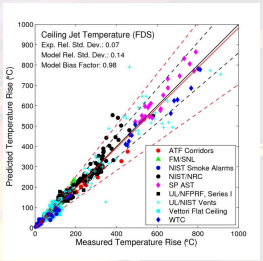
ACRS Recommendation 1: Provide probability distributions







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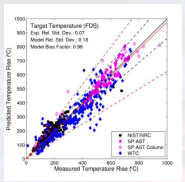
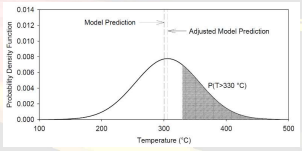


(Left) Typical results from a validation study. The black lines indicate the experimental uncertainty and the red lines indicate the model uncertainty.

(Below) Given a model prediction of 300 °C, what is the probability that the actual temperature might exceed 330 °C, the failure temperature of the given target?



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Models of Interest

Summary of NRC/EPRI validation study, NUREG-1824, Supplement 1

Quantities of Interest

Output Quantity	Empirical Correlations		CFAST		MAGIC		FDS		Exp
	Corr.	δ	δ	δ_{sd}	δ	δ_{sd}	δ	δ_{sd}	δ_E
HGL Temp. Rise, Natural	MQH	1.17	0.15	1.20	0.30	1.12	0.32	1.81	0.12	0.07
HGL Temp. Rise, Forced	FPA	1.29	0.32	1.15	0.20	1.09	0.17	1.21	0.22	0.07
	DB	1.16	0.25							
HGL Temp. Rise, Closed	Beyler	1.04	0.37	0.99	0.09	1.07	0.16	1.29	0.13	0.07
HGL Depth	ASET/YT	-	-	1.04	0.33	1.12	0.29	1.03	0.09	0.05
Ceiling Jet Temp. Rise	Alpert Unconfined	0.95	0.17	1.10	0.33	1.04	0.45	0.95	0.14	0.07
	Alpert Compartment	0.31	0.40							
Plume Temp. Rise	Heskestad	0.84	0.33	1.00	0.20	1.04	0.20	1.20	0.21	0.07
	McCaffrey	0.90	0.31							
Oxygen Concentration	N/A			1.00	0.15	0.93	0.22	1.01	0.11	0.09
Smoke Concentration	N/A			1.16	0.60	1.71	0.95	2.63	0.59	0.19
Pressure Rise	N/A			1.26	0.85	1.45	0.45	0.95	0.27	0.21
Target Temp. Rise	Steel	1.29	0.45	1.59	0.84	1.69	0.39	0.99	0.18	0.07
Target Heat Flux	Point Source	1.44	0.47	0.93	1.16	0.85	0.65	0.98	0.25	0.11
	Solid Flame	1.17	0.44							
Surface Temp. Rise	N/A			1.05	0.28	0.95	0.29	0.99	0.12	0.07
Surface Heat Flux	N/A			0.95	0.34	0.79	0.35	0.92	0.15	0.11
Cable Failure Time	THIEF	0.90	0.11	-	-	-	-	1.10	0.18	0.12
Sprinkler Activation Time	Sprinkler	1.11	0.41	0.80	0.21	0.93	0.20	0.93	0.15	0.06
Smoke Detector Activation Time	Temp. Rise	0.95	0.57							
	Mitke	0.85	0.80	1.12	0.46	1.04	0.36	0.85	0.28	0.34
	Mowrer	0.11	0.50							

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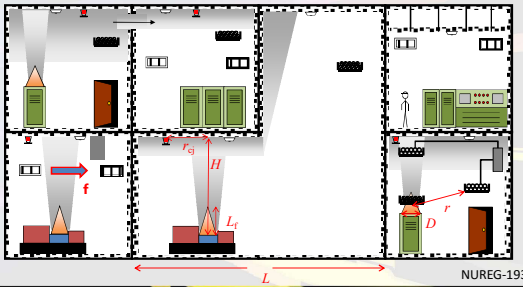
ACRS Recommendation 2: Provide ranges of normalized parameters



NUREG-1934

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For what range of parameters are the models validated?

Experiment	$\dot{Q}$ (kW)	D (m)	H (m)	$\dot{Q}^*$	L_f/H	φ	W/H	L/H	r_{cj}/H	r/D
ATF Corridors	50-500	0.5	2.4	0.3-3.3	0.3-0.9	0.0-0.1	0.6	7.1	0.6-6.0	N/A
Fleury	100-300	0.3-0.6	Open	0.3-0.5	Open	Open	Open	Open	Open	0.8-8
FM/SNL	470-2000	0.9	6.1	0.6-2.4	0.3-0.6	0.0-0.2	2.0	3.0	0.2-0.3	N/A
LLNL	50-400	0.6	4.5	0.2-1.5	0.1-0.4	0.1-0.4	0.9	1.3	0.3-1.0	N/A
NBS Multi-Room	110	0.3	2.4	1.5	0.5	0.0	1.0	5.1	N/A	N/A
NIST/NRC	350-2200	1.0	3.8	0.3-2.0	0.3-1.0	0.0-0.3	1.9	5.7	0.3-2.1	2-4
SP AST	450	0.3	2.4	6.1	0.9	0.1	1.0	1.5	N/A	N/A
Steckler	32-158	0.3	2.1	0.8-3.8	0.3-0.7	0.0-0.5	1.3	1.3	N/A	N/A
UL/NFPRF	4400-10000	1.0	7.6	4.0-9.1	0.7-1.0	NA	4.9	4.9	0.6-3.9	N/A
UL/NIST Vents	500-2000	0.9	2.4	0.7-2.6	0.8-1.6	0.2-0.6	1.8	2.5	1.0-2.3	N/A
USN Hawaii	100-7700	0.3-2.5	15	0.7-1.3	0.1-0.4	NA	4.9	6.5	0-1.2	N/A
USN Iceland	100-15700	0.3-3.4	22	0.7-1.3	0.0-0.3	NA	2.1	3.4	0-1.0	N/A
Vettori Flat	1055	0.7	2.6	2.5	1.1	0.3	2.1	3.5	0.6-2.9	N/A
Vettori Sloped	1055	0.7	2.5	2.5	1.2	0.3	2.2	2.9	N/A	N/A
VTT Hall	1800-3640	1.2-1.6	19	1.0-1.1	0.2	0.0-09	1.0	1.4	0-0.6	N/A
WTC	1970-3240	1.6	3.8	0.6-0.9	0.8-1.1	0.3-0.5	0.9	1.8	0-0.8	0.3-1.3

NUREG-1824, Supplement 1

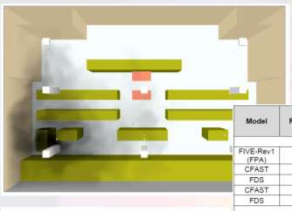
Example A, NUREG-1934, *Fire Model User's Guide*

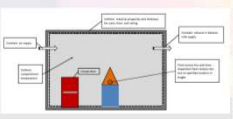
Fire in the Main Control Room

"… approximate the length of time that the main control room remains habitable after the start of a fire within a low-voltage control cabinet."

Given the heat release rate, geometric parameters, and other information, does the hypothetical fire scenario "fit" within the parameter space of actual fires used in the V&V study? In other words, have the models been validated for this hypothetical scenario?

Quantity	Normalized Parameter Calculation		NUREG-1824 Validation Range	In Range?
Fire Froude Number	$\frac{\dot{Q}}{\rho_\infty c_p T_\infty D^{5/2}\sqrt{g}} = \frac{702\ \text{kW}}{(1.2\ \text{kg/m}^3)(1.0\ \text{kJ/kg/K})(293\ \text{K})(0.4^{5/2}\ \text{m}^{5/2})\sqrt{9.8\ \text{m/s}^2}} = 6.2$		0.4 – 2.4	No
Flame Height, $H_f + L_f$, relative to the Ceiling Height, H_c	$\frac{H_f + L_f}{H_c} = \frac{2.1\ \text{m} + 2.7\ \text{m}}{5.2\ \text{m}} = 0.9$ $L_f = D\left(3.7\,Q^{*2/5} - 1.02\right) = 0.4\ \text{m}\ (3.7 \times 6.2^{2/5} - 1.02) = 2.7\ \text{m}$		0.2 – 1.0	Yes
Ceiling Jet Radial Distance, r_c, relative to the Ceiling Height, H_c	N/A – Ceiling jet targets are not included in simulation.		1.2 – 1.7	N/A
Equivalence Ratio, φ, of the room, based on Forced Ventilation of Purge Mode	$\varphi = \frac{\dot{Q}}{\Delta H_c \dot{m}_a} = \frac{702\ \text{kW}}{13,100\ \text{kJ/kg} \times 3.7\ \text{kg/s}} = 0.014$ $\dot{m}_a = \overline{v}_0\ \rho_\infty Y = 0.23 \times 1.2\ \text{kg/m}^3 \times 15.4\ \text{m}^2/\text{s} = 3.7\ \text{kg/s}$		0.04 – 0.8	No
Compartment Aspect Ratio	$\frac{L}{H_c} = \frac{24.6\ \text{m}}{5.2\ \text{m}} = 4.7$	$\frac{W}{H_c} = \frac{16.2\ \text{m}}{5.2\ \text{m}} = 3.1$	0.6 – 5.7	Yes
Target Distance, r, relative to the Fire Diameter, D	$\frac{r}{D} = \frac{0.8\ \text{m}}{0.4\ \text{m}} = 22$		2.2 – 5.7	No





Model	Bias Factor, $\hat{B}$	Standard Deviation, σ_M	Ventilation	Predicted Value	Critical Value	Probability of Exceeding
Temperature (°C), Initial Value = 20 °C						
FIVE-Rev1 (FPA)	1.56	0.32	Purge	70	95	0.000
CFAST	1.06	0.12		61	95	0.000
FDS	1.03	0.07		48	95	0.000
CFAST	1.06	0.12	No Vent.	82	95	0.009
FDS	1.03	0.07		70	95	0.000
Heat Flux (kW/m²)						
FIVE-Rev1	1.42	0.55	Purge	0.4	1	0.000
CFAST	0.81	0.47		0.1	1	0.000
FDS	0.85	0.22		0.2	1	0.000
CFAST	0.81	0.47	No Vent.	0.6	1	0.228
FDS	0.85	0.22		0.4	1	0.000
Optical Density (m⁻¹)						
CFAST	2.65	0.63	Purge	7.8	3	0.471
FDS	2.7	0.55		0.5	3	0.000
CFAST	2.65	0.63	No Vent.	54	3	0.912
FDS	2.7	0.55		31	3	0.909